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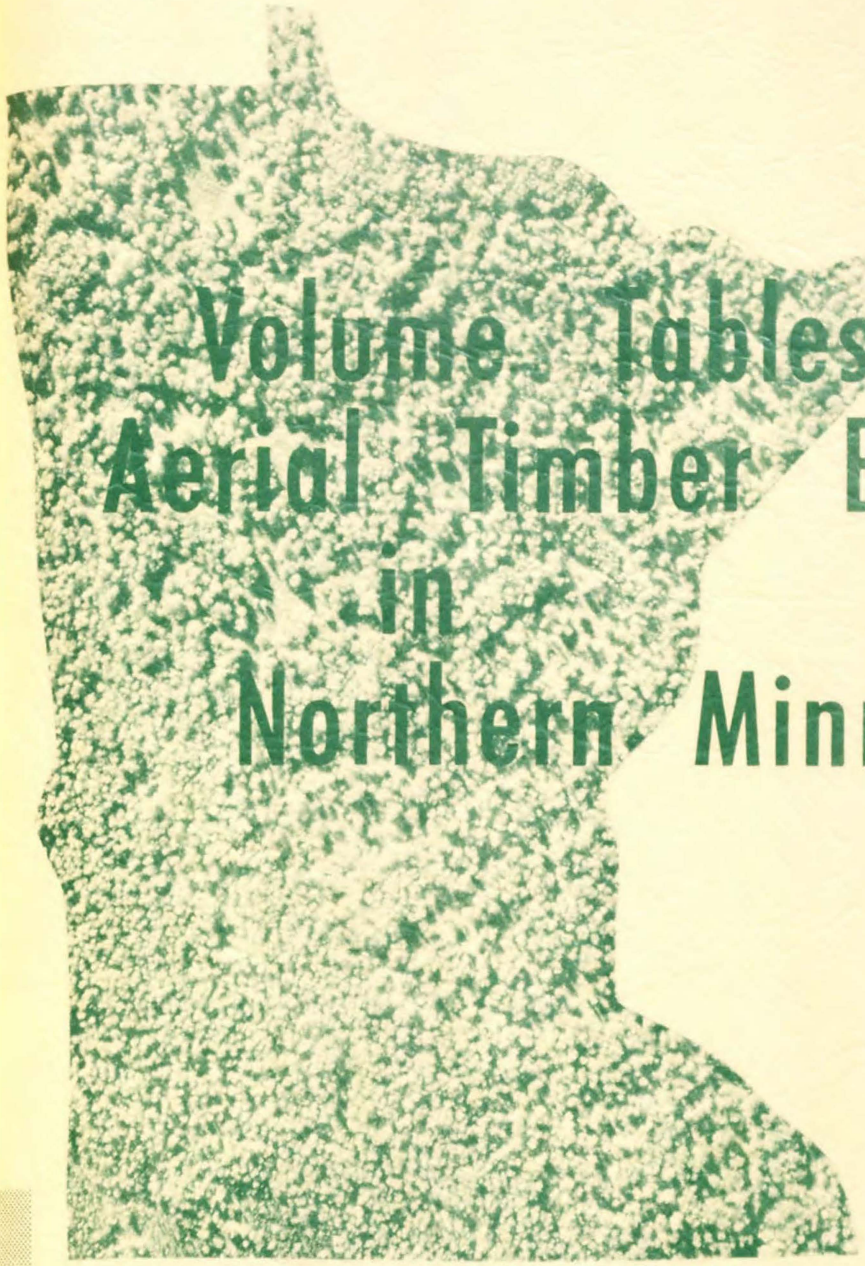

Volume Tables for Aerial Timber Estimating in Northern Minnesota

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In recent years, aerial photo interpretation has become an important tool in Forest Survey work. As part of the research aimed at improving survey techniques, the University of Minnesota School of Forestry and the U.S. Forest Service conducted a cooperative study on the application of aerial volume tables to northern Minnesota forests.

The Lake States Forest Experiment Station (maintained at St. Paul 1, Minn., by the Forest Service, U.S. Department of Agriculture, in cooperation with the University of Minnesota) is pleased to publish the study results as part of its contribution in this joint effort.

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Figure 1.-- Sample stereogram from Carlton County, Minnesota, illustrating the type of aerial photography used in this study. Exposures were made on panchromatic film in September 1957, at a scale of 4 inches per mile. Dark-toned trees are conifers; lighter gray crowns are hardwoods. Courtesy of Mark Hurd Aerial Surveys, Inc.

Volume Tables
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by

Gene Avery[1/] and Merle P. Meyer[2/]

Introduction

Expanding uses for aerial photographs in forest inventories emphasize the need for reliable aerial volume tables. Though several good tables have been published during the past 10 years, none were compiled specifically for Minnesota forests. As aerial volume tables constructed for one area have sometimes been successfully applied to other areas, a study was made in 1959 to evaluate three existing tables for their applicability to northern Minnesota forest conditions.

Results of the study are presented in three parts: The first explains how certain tables from other forest regions may be used to estimate gross stand volume in this State. Second, a new preliminary table for northern Minnesota is presented, based on data accumulated during the experiment. This composite table may be used to derive cubic volumes for both conifer and hardwood stands.

Third, as aerial timber volume estimates are most commonly used in conjunction with measurements from a smaller number of field plots, a method for integrating photo and field determinations of timber volume is presented in the final section of this paper.

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Location and Measurement of Field Plots

In January 1959, fifty 1-acre field plots were located in or near the University of Minnesota's Research Forest near Cloquet. This area of about 30 square miles in Carlton County was selected to take advantage of recent aerial photography and to facilitate the collection of field data by University personnel.

Plot locations were pin-pointed on aerial photographs at the time of field establishment. They were chosen to span a wide range of volume classes, and were equally distributed among conifer and hardwood stands. Forest types represented were aspen-birch, northern hardwoods, jack pine, Norway pine, white pine, black spruce, tamarack, and spruce-fir.

Gross cubic volumes were determined at each field plot by point-sampling techniques (4).[3/] Sample trees were selected for measurement by use of a wedge prism having a basal area factor of 10 square feet per acre. To get an adequate representation of stand conditions within the acre, tree tallies were made at plot center and at four satellite points 80 feet distant in the cardinal directions. All live-crowned trees 5.0 inches d.b.h. and larger were tallied by 2-inch diameter classes and number of 8-foot bolts. Data were recorded on cumulative tally cards developed from composite volume tables for the Lake States (3, 8). Stand volume per acre was calculated from an average of the five tallies. Gross plot volumes ranged from 230 to 4,120 cubic feet per acre.

3/ Underscored numbers in parentheses refer to Literature Cited, p. 16.

Photo Interpretation Procedure

Photo interpretation was performed by advanced photogrammetry students at the School of Forestry, University of Minnesota. To assure that all participants attained a minimum level of competence, each was given 34 hours of preliminary interpretation training. This included stereoscopic measurements on three different scales of aerial photography (1:6,000; 1:11,000; and 1:20,000).

Aerial photographs used for the 50 test plots were taken in September 1957 by Mark Hurd Aerial Surveys, Inc., of Minneapolis. Thus, only one growing season had elapsed prior to the collection of field measurements. As illustrated in figure 1 (facing page 1), exposures were made on panchromatic film at a nominal scale of 1:15,840. On each of the photo plots, 18 interpreters determined the following items:

a. Forest type: a classification of each plot as largely composed of hardwood or coniferous trees.

b. Average total height of the four tallest trees on each plot, measured with an Abrams parallax bar (fig. 2).

c. Average crown diameter of the dominant stand, measured with a graduated dot-type crown scale.

d. Crown closure percent[4/] of the stand, estimated in 10-percent classes by ocular comparison with printed density scales.

4/ Relationship of the forest canopy area to the total plot area; also referred to as crown cover or crown density.

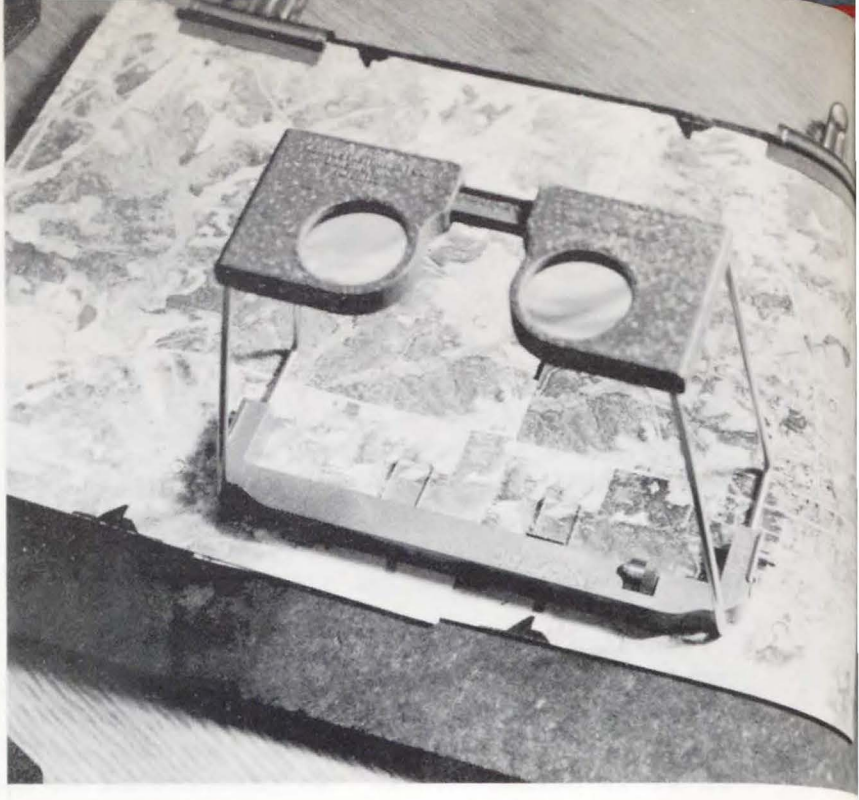

Figure 2.--Abrams lens stereoscope with parallax bar attached for measuring tree heights.

Comparison of Existing Tables

Individual Estimates of Volume

Three available aerial volume tables were used to derive plot volumes from stereoscopic measurements. These tables had been originally compiled for Rocky Mountain conifers (5), Kentucky hardwoods (6), and Mississippi pines and hardwoods (1). For the reader's convenience, all three tables are reproduced in the Appendix (tables 7-9).

One set of volume estimates was obtained by applying the Rocky Mountain table to conifer plots and the Kentucky table to hardwood plots. A second set of volumes was tabulated by using the Mississippi composite table for all plots, irrespective of forest type. Average cubic volumes and standard errors for the 50 test plots were computed for each interpreter and volume table. A comparison of these individual estimates with average field volume is presented in table 1.

It is noteworthy that in both tabulations, 12 of the 18 photo estimates were within 15 percent of the average field volume. Maximum differences of approximately 30 percent also occurred independently of the aerial volume table used. Individuals tended to produce either high or low results on both sets of estimates, but the overall pattern is one of a near balance between plus and minus deviations. In only one instance did both estimates by an interpreter differ more than 15 percent from the average field volume.

Table 1.--Comparison of mean photo volume estimates on 50 plots in Carlton Co., Minn.; average field volume is 1,262 cubic feet per acre

Interpreter	Photo estimates made from:			
	Rocky Mountain and Kentucky tables [1/]		Mississippi composite table	
	Mean photo volumes and their standard errors	Difference [2/]	Mean photo volumes and their standard errors	Difference [2/]
	Cubic feet	Percent	Cubic feet	Percent
1	994 ± 91	- 21.2	923 ± 64	- 26.9
2	1,652 ± 151	+ 30.9	1,337 ± 81	+ 5.9
3	1,357 ± 122	+ 7.5	1,215 ± 69	- 3.7
4	1,253 ± 118	- 0.7	1,152 ± 65	- 8.7
5	1,539 ± 154	+ 21.9	1,287 ± 80	+ 2.0
6	1,560 ± 156	+ 23.6	1,304 ± 100	+ 3.3
7	1,420 ± 114	+ 12.5	1,263 ± 70	+ 0.1
8	1,266 ± 147	+ 0.3	888 ± 70	- 29.6
9	1,431 ± 141	+ 13.4	1,331 ± 93	+ 5.5
10	1,103 ± 94	- 12.6	955 ± 56	- 24.3
11	1,340 ± 148	+ 6.2	1,111 ± 63	- 12.0
12	1,075 ± 94	- 14.8	970 ± 59	- 23.1
13	1,248 ± 107	- 1.1	990 ± 64	- 21.6
14	1,234 ± 112	- 2.2	1,138 ± 58	- 9.8
15	1,537 ± 143	+ 21.8	1,421 ± 77	+ 12.6
16	1,221 ± 115	- 3.2	1,136 ± 64	- 10.0
17	1,541 ± 100	+ 22.1	1,353 ± 78	+ 7.2
18	1,108 ± 78	- 12.2	898 ± 48	- 28.8

1/ Volumes for conifer and hardwood plots derived respectively from Rocky Mountain and Kentucky aerial volume tables.

2/ Difference between average photo and field volumes, expressed as a percent of field volume.

For all 18 interpreters, average volumes derived from the Rocky Mountain and Kentucky tables were 5.2 percent higher than the average field volume. By comparison, average volumes based on the Mississippi table were 9.0 percent less than the field average of 1,262 cubic feet per acre. The difference in the two sets of aerial volume estimates was statistically significant. Viewing these results in conjunction with the standard errors shown in table 1, it was concluded that the Rocky Mountain and Kentucky tables were more sensitive to changes in volume and had less bias in application than the Mississippi table. The lone factor favoring the Mississippi table was its universal application to both conifer and hardwood stands.

Group Estimates of Volume

To determine which table was best for the 18 interpreters as a group, individual measurements of height, crown diameter, and crown closure were averaged. These average values were used to read a new set of volumes from the three tables as previously described. Comparisons of plot volumes and means are shown in table 2. Neither of the mean photo estimates differed significantly from the field average; one coincided precisely with the actual volume, while the other was 108 cubic feet low.

To compare the accuracy of individual plot estimates, the 50 field plot volumes were graphed over the two sets of corresponding photo volumes. Linear regressions of the form, $Y = a + bX$, were fitted to each set of plotted points by the method of "least squares." The "F" test showed both relationships to be highly significant (table 10, Appendix).

The mean squared residual[5/] for the regression based on Rocky Mountain and Kentucky tables was significantly smaller than that derived from the Mississippi data. This indicates that the former estimates more nearly agreed with their paired field volumes than did the latter group. A re-inspection of table 2 bears out this conclusion. It was again concluded that the use of the Rocky Mountain table for conifers and the Kentucky table for hardwoods produced better estimates of individual plot volumes than did the Mississippi composite table. Regardless of the table used, photo estimates should be adjusted by occasional ground checks of plot volume.

5/ The mean squared residual corresponds to the squared standard error of estimate for the derived regression equation. It is a measure of the variation in the dependent variable (field volume, in this case) unaccounted for by the regression of Y on X.

Table 2.--Comparison of field plot volumes with group estimates derived from aerial volume tables

(In cubic feet per acre)

Plot number	Field volume	Photo estimate from: Rocky Mountain and Kentucky tables	Photo estimate from: Mississippi table	Plot number	Field volume	Photo estimate from: Rocky Mountain and Kentucky tables	Photo estimate from: Mississippi table
1	350	620	450	26	2,710	3,100	1,270
2	3,750	4,200	2,060	27	370	600	560
3	2,200	1,700	1,480	28	1,540	1,400	1,190
4	4,120	3,500	2,080	29	810	780	1,300
5	1,480	1,950	1,510	30	820	700	1,140
6	760	1,040	1,190	31	930	920	1,550
7	1,210	1,350	1,200	32	1,610	1,400	1,130
8	600	750	630	33	850	1,000	940
9	1,360	1,420	1,650	34	1,200	1,000	940
10	1,250	850	1,390	35	1,590	1,450	1,750
11	1,910	2,250	1,510	36	1,370	1,280	1,130
12	1,110	1,300	1,060	37	1,050	1,420	1,000
13	410	750	630	38	630	900	770
14	1,280	1,250	1,130	39	330	650	950
15	480	720	1,130	40	690	680	930
16	1,160	1,000	540	41	530	600	840
17	2,620	2,450	1,780	42	660	1,050	970
18	890	830	1,350	43	1,220	750	1,140
19	1,920	1,350	1,130	44	1,760	1,100	730
20	980	1,050	750	45	570	850	630
21	1,400	1,700	1,300	46	850	700	640
22	230	500	610	47	1,890	1,950	1,300
23	1,970	1,480	1,900	48	880	1,000	950
24	1,650	1,420	1,650	49	1,280	750	1,140
25	1,290	920	1,550	50	600	720	1,130
	Mean volume per acre				1,262	1,262	1,154

Construction of a New Aerial Volume Table

Multiple regression techniques were used to derive a new aerial volume table for northern Minnesota. Field plot volumes were first graphed over average photo heights, crown closure percents, and crown diameters to determine the relationships between dependent and independent variables.[6/] A linear trend was indicated for average heights and crown closures, but there was little or no correlation evident between volume and average crown diameter. This variable was thereby eliminated, and a multiple regression based on height and crown closure was developed.

Because of the limited number of observations available, conifer and hardwood plots were combined in computing the regression. As indicated in the Appendix, table 11, the "F" test showed the relationship to be highly significant. The prediction equation was then used to compile a composite aerial volume table by 5-foot height classes and 5-percent crown closure intervals (table 3).

It should be remembered that this is a preliminary table only, and the extent of its application to forest stands outside the test area has not been determined. A preliminary analysis showed that the table may be expected to read 10 to 15 percent high for pure hardwood stands and correspondingly low in pure coniferous areas. Smaller deviations should result where conifers and hardwoods occur in approximately equal proportions.

Foresters interested in using the Minnesota aerial volume table may test its value in specific areas by following the procedures outlined for the Rocky Mountain, Kentucky, and Mississippi tables. A minimum of 40 to 50 field plots must be measured for a good comparative analysis, and all photo evaluations should be made by two or more interpreters. Differences of less than 15 percent between mean photo and field volumes are considered acceptable for most aerial timber estimates.

6/ Field plot volume was the dependent variable; photo measurements of height, crown closure, and crown diameter comprised the independent variables.

Table 3.--Composite aerial volume table for northern Minnesota[1/]

(In gross cubic feet per acre[2/] [3/])

Average total height (feet)	Crown closure percent									
	5	15	25	35	45	55	65	75	85	95
30	40	120	200	280	360	440	520	600	680	760
35	80	190	300	410	520	630	740	850	960	1,070
40	180	310	440	570	700	830	960	1,090	1,220	1,350
45	460	590	720	850	980	1,110	1,240	1,370	1,500	1,630
50	740	870	1,000	1,130	1,260	1,390	1,520	1,650	1,780	1,910
55	1,020	1,150	1,280	1,410	1,540	1,670	1,800	1,930	2,060	2,190
60	1,300	1,430	1,560	1,690	1,820	1,950	2,080	2,210	2,340	2,470
65	1,580	1,710	1,840	1,970	2,100	2,230	2,360	2,490	2,620	2,750
70	1,860	1,990	2,120	2,250	2,380	2,510	2,640	2,770	2,900	3,030
75	2,140	2,270	2,400	2,530	2,660	2,790	2,920	3,050	3,180	3,310
80	2,420	2,550	2,680	2,810	2,940	3,070	3,200	3,330	3,460	3,590
85	2,700	2,830	2,960	3,090	3,220	3,350	3,480	3,610	3,740	3,870
90	2,980	3,110	3,240	3,370	3,500	3,630	3,760	3,890	4,020	4,150
95	3,260	3,390	3,520	3,650	3,780	3,910	4,040	4,170	4,300	4,430
100	3,540	3,670	3,800	3,930	4,060	4,190	4,320	4,450	4,580	4,710

1/ Based on fifty 1-acre plots in Carlton County, Minn. Heavy lines indicate limits of basic data.

2/ Gross volumes are inside bark and include all trees 5.0 inches d.b.h. and larger from stump to a variable top diameter not less than 4.0 inches i.b.

3/ Volumes may be converted to rough cords per acre by dividing by 80.

Combining Aerial and Ground Volume Estimates

Volume estimates derived wholly through aerial photo interpretation are rarely relied upon except in remote and inaccessible regions. Ordinarily, the forest manager desires an inventory design that efficiently combines the best features of both aerial and ground cruises.

Whether the determination of standing timber volume can be more efficiently fulfilled through a system of photo-volume stratification is dependent on the following items:

(1) Quality and age of available aerial photography.

(2) Adaptability of aerial volume tables to stand conditions.

(3) Ability of interpreters in recognizing volume strata.

(4) Extent to which total variance is reduced by photo stratification.

(5) Relative costs of photo and ground plots.

In the system of double sampling (7) discussed here, a large number of photo plots are interpreted and stratified on a volume-per-acre basis. From each volume class, a subsample of ground plots is drawn to obtain mean volume for that stratum. Total volume, the basic objective, is derived by multiplying the mean volume for each stratum by the forest area for that class.

The intensity of any timber cruise is ordinarily governed by either the total expenditure budgeted for the inventory or by a statistical standard of accuracy. Only the first approach is treated in the example that follows, though both have been fully described by Bickford (2). Computations are based primarily on Forest Survey data from the Northeastern Forest Experiment Station,[7/] but the methods presented are applicable in any region.

7/ Maintained at Upper Darby, Pa., by the Forest Service, U.S. Dept. of Agriculture.

A sample problem.--Assume that an inventory is planned for a tract of 10,000 acres, of which 7,500 acres have been classified as forest on aerial photographs. Ten cents per acre has been budgeted for the inventory, giving a total allowable expenditure of $0.10 x 7,500 = $750.

Cubic volume classes.--First, a set of photo-volume strata should be formulated. Five to ten cubic-foot classes are commonly recognized, each having a progressively wider span of volume (table 4). The strata should roughly conform to the expected range and distribution of volumes in the area of application; otherwise, most of the plots might fall into one or two classes and nullify the primary objectives of stratification.

Table 4.--Suggested cubic volume strata for use in aerial volume classification

(In gross cubic feet per acre)

Class	Range of volume	Standard deviation[1/]
I	1 to 350	100
II	351 to 750	200
III	751 to 1,500	400
IV	1,501 to 2,500	800
V	2,501 or more	1,000

1/ Assumed values based on previous studies in eastern United States.

Costs of field and photo plots.--Such costs will obviously vary from one area to another and should be determined locally. On extensive inventories such as the Forest Survey, the cost of locating and measuring a field plot may be expected to be about 100 times that of interpreting a forest photo plot. Accordingly, field plots will be assumed to cost $20 each, forest photo plots will be prorated at $0.20, and nonforest plots at $0.02.

Number of ground and photo plots.--The number of ground plots needed may be determined by this formula (7):

$$\text{Ground plots (G)} = \frac{Ca}{aA + b\sqrt{AB}}$$

Where: C = total cost budgeted for the area.

A = cost of a ground plot.

B = average cost of interpreting forest and nonforest photo plots.

a = a measure of the standard deviation within photo volume classes.

b = a measure of the variance between photo volume classes.

Items C, A, and B can be ordinarily established on the basis of local conditions. Deriving values for a and b is more difficult, however, for these parameters are dependent on the variability of forest conditions, the quality of available aerial photography, and the ability of photo interpreters. In this example, a is assigned a value of 400 and b is taken as 600.[8/] The formula now becomes:

$$\text{Ground plots (G)} = \frac{400C}{400A + 600\sqrt{AB}}$$

8/ In practice, a and b cannot be accurately determined until after completion of the timber cruise. Values given above should be reliable as initial approximations, as they are large enough to overestimate the number of plots required under most forest conditions. They may also be computed by formulae (2):

$$a = \sum P_i S_i \quad \text{and} \quad b = \sqrt{\sum P_i \left(X_i - \bar{X}\right)^2}$$

Where: P_i is the proportion in the i th class, S_i is the standard deviation of volume of the i th class, X_i is the mean volume of the i th class, and $\bar{X}$ is the mean volume for the area.

The average cost of interpreting photo plots (both forest and nonforest) is computed by this relationship:

$$B = FB_1 + (1 - F)\, B_2$$

Where: F = proportion of total area in forest (0.75 in this case).

B_1 = cost of a forest photo plot ($0.20).

B_2 = cost of a nonforest photo plot ($0.02).

Thus: $B = .75\ (.20) + (1 - .75)(.02) = \$0.16$ per photo plot.

And, $$G = \frac{400(750)}{400(20) + 600\sqrt{20(0.16)}} = 33.06 \text{ ground plots}$$

Thus, 33 ground plots are required for the inventory. The number of photo plots needed is determined as follows:

$$\text{Photo plots } (P) = \frac{C - GA}{B} = \frac{750 - 33(20)}{0.16} = 563 \text{ photo plots.}$$

Distribution of photo plots.--If 16 aerial photos are required to stereoscopically cover the 10,000-acre area, there would be 563 ÷ 16 = 35.2 (or 36) photo plots located within the effective areas[9/] of each print. A 4x9-dot-grid template could be used to pinpoint each location, resulting in an actual total of 36 x 16, or 576 photo plots. One-acre circular plots are commonly used for photo interpretation, though it is usually necessary to rely on smaller ground samples of 1/5 to 1/4 acre.

Each photo plot should be studied stereoscopically and necessary measurements made for entering the appropriate aerial volume table. In this example, the volume read from the table merely determines the cubic-volume stratum for each plot. As shown in table 5, there were 141 of the 576 photo plots placed in Class I, 204 in Class II, and so on.

Distribution of ground plots.--After all photo plots have been classified, the next step is the distribution of the 33 ground plots by volume classes and the determination of sampling intervals for each class. Table 5 was prepared to facilitate this step-by-step procedure. The relatively simple computations involved are

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9/ On 9x9-inch contact prints having 60 percent forward overlap and 30 percent sidelap, these central effective areas will be rectangles about 3.6 by 6.3 inches in size.

illustrated in the column headings. Two of the 33 ground plots were taken in Class I, 7 in Class II, 6 in Class III, 10 in Class IV, and 8 in Class V.

The sampling interval is used to decide which photo plots in each class will also become ground plots. It is computed by dividing the number of photo plots by the number of ground plots in each volume class. In Class I, for example, there are 141 photo plots and only two ground plots. Thus, every 70th photo plot will be a ground plot. Next, a random number between 1 and 70 is selected. If this number is 55, then plots 55 and 125 (55 + 70) in Class I would be chosen for field measurement. The same procedure is repeated for all other classes.

Table 5.--Distribution of photo and ground plots by cubic volume strata

Photo volume class 1/	Photo plots P	Proportion of total R	Standard deviation S 1/	Proportioned deviation R X S	Ground plots G 2/	Sampling interval P ÷ G
I	141	0.245	100	24	2	70
II	204	.354	200	71	7	29
III	98	.170	400	68	6	16
IV	82	.142	800	114	10	8
V	51	.089	1,000	89	8	6
Totals	576	1.000	--	366	33	--

1/ From table 4.
2/ Computed for each class by (33) $\frac{R \times S}{366}$.

Volume summary.-- After all ground plots have been measured, volumes are summarized for the tract. First, the forest area for each stratum is determined. This can be done by a separate dot grid count or by using the proportion of the interpreted plots occurring in each class (table 5). The latter procedure was followed here. The final step is simply the multiplication of average field volume per acre by the number of acres in each class. Calculations are illustrated in table 6.

Table 6.--Calculation of total cubic volumes by original photo classifications

Photo volume class	Forest area by classes 1/	Average volume per acre 2/	Extended volume by classes
	Acres	Cubic feet	Cubic feet
I	1,837.5	180	330,750
II	2,655.0	575	1,526,625
III	1,275.0	1,120	1,428,000
IV	1,065.0	1,745	1,858,425
V	667.5	2,860	1,909,050
Totals	7,500.0	--	7,052,850

1/ Proportion of photo plots in each class multiplied by the total forested acreage.

2/ Volumes from ground plot measurements.

For additional information on statistical compilations briefed here, readers should refer to original articles by Bickford (2) and Neyman (7).

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Table 7.--Aerial volume table for Rocky Mountain conifers[1/] [2/]

(In tens of cubic feet per acre)

Average stand height (feet)	Crown cover (Percent)									
	5	15	25	35	45	55	65	75	85	95
4- TO 7-FOOT CROWN DIAMETER										
30		10	30	45	55	65	75	85	100	115
35		20	40	55	65	75	85	100	120	140
40		30	50	65	75	85	100	115	140	165
45	5	40	60	75	85	95	110	130	155	180
50	10	50	70	85	100	115	135	160	185	210
55	20	60	85	105	120	140	160	185	210	235
60	35	80	110	135	160	180	200	225	250	275
65	50	105	140	170	195	215	235	255	280	305
8- TO 12-FOOT CROWN DIAMETER										
30		15	35	50	60	70	80	95	120	135
35		25	45	60	75	85	95	110	130	150
40		35	55	70	85	95	105	125	150	175
45		40	65	80	95	110	125	145	170	195
50	10	50	70	95	110	125	145	170	195	215
55	30	70	90	110	130	150	175	200	225	250
60	45	90	120	150	175	195	215	235	255	265
65	70	120	160	190	210	230	250	270	290	310
70	90	160	200	230	250	270	285	300	320	330
75	120	200	240	270	285	300	320	340	360	380
80	170	250	280	310	330	345	360	380	400	420
85	220	300	330	355	375	395	415	435	455	475
13- TO 17-FOOT CROWN DIAMETER										
30		20	40	55	70	80	90	105	120	135
35		30	50	70	80	90	105	120	150	170
40		40	60	80	90	100	125	145	170	195
45	10	50	70	85	100	115	135	160	185	210
50	20	60	85	100	115	135	160	185	210	235
55	30	75	100	125	150	170	190	215	235	255
60	50	100	130	160	185	205	225	245	265	285
65	75	130	170	200	220	240	260	280	300	320
70	100	170	210	240	260	275	290	310	330	350
75	130	210	250	275	295	315	330	350	370	390
80	180	260	290	320	340	360	375	390	410	430
85	230	310	345	370	390	405	420	440	460	480
90	280	360	390	415	435	450	465	485	505	525
95	330	410	440	460	480	500	520	540	560	580
100	370	450	485	515	535	555	575	595	615	635

Average stand height (feet)	Crown cover (Percent)									
	5	15	25	35	45	55	65	75	85	95
18- TO 22-FOOT CROWN DIAMETER										
30		30	50	70	80	90	105	120	140	160
35		40	65	80	90	105	120	140	160	180
40	10	50	75	90	105	120	140	160	180	200
45	20	60	85	105	120	140	160	180	200	220
50	35	75	100	120	140	160	180	205	225	245
55	45	85	115	140	165	190	210	230	250	270
60	65	115	150	180	205	225	245	265	285	305
65	85	150	190	220	240	260	275	290	310	330
70	110	190	230	255	275	290	310	330	350	370
75	160	240	270	295	310	325	345	365	385	405
80	195	275	305	330	350	370	390	410	430	450
85	250	330	360	385	405	425	440	455	475	495
90	290	370	405	430	450	470	485	505	530	550
95	340	420	450	480	500	520	540	560	580	600
100	390	470	500	530	550	570	590	610	630	650
105	460	540	580	600	620	640	655	670	685	705
110	520	600	640	660	680	700	720	740	760	780
23-FOOT AND LARGER CROWN DIAMETER										
30	10	50	75	90	105	125	145	165	190	215
35	20	65	85	105	125	145	165	185	210	235
40	30	75	100	120	140	160	180	205	230	255
45	40	85	110	135	160	180	200	225	250	275
50	55	100	130	160	185	205	225	245	265	285
55	70	120	160	190	210	230	250	270	290	310
60	85	155	195	225	245	265	285	305	325	345
65	120	190	230	255	275	290	310	330	350	370
70	155	225	265	290	310	330	345	365	385	405
75	205	275	305	330	350	365	380	400	420	440
80	245	315	345	370	390	405	420	440	460	480
85	290	360	395	420	440	455	470	490	510	530
90	340	410	440	465	485	505	525	545	565	585
95	385	455	485	515	535	555	575	595	615	635
100	440	510	540	570	590	610	625	640	660	680
105	510	580	610	640	655	670	685	700	715	730
110	660	640	670	690	705	720	735	750	770	785
115	615	690	720	740	760	775	790	805	820	835

1/ Reprinted from (5).

2/ Based on 168 field plots taken in southeastern Idaho, southwestern Wyoming, and northeastern Utah. Aggregate deviation: Table 1.5% low. Standard error of estimate: ± 48% of average plot volume.

Table 8.--Aerial volume table for Kentucky hardwoods[1/] [2/]

(In cubic feet per acre)

Average stand height (feet)	Crown closure percent								
	15	25	35	45	55	65	75	85	95
10- TO 14-FOOT AVERAGE CROWN DIAMETER									
30	300	375	450	475	500	570	635	700	770
40	350	425	500	550	600	650	700	750	800
50	400	475	550	625	700	770	835	900	970
60	550	675	800	875	950	1,035	1,115	1,200	1,285
70	900	1,075	1,250	1,325	1,400	1,470	1,535	1,600	1,670
15- TO 19-FOOT AVERAGE CROWN DIAMETER									
30	350	400	450	500	550	620	685	750	820
40	400	450	500	575	650	720	785	850	920
50	450	525	600	675	750	835	920	1,000	1,085
60	600	725	850	950	1,050	1,100	1,150	1,200	1,250
70	1,000	1,150	1,300	1,400	1,500	1,550	1,600	1,650	1,700
80	1,500	1,625	1,750	1,825	1,900	1,970	2,035	2,100	2,170
20- TO 29-FOOT AVERAGE CROWN DIAMETER									
40	500	625	750	850	950	1,035	1,115	1,200	1,285
50	600	750	900	1,000	1,100	1,185	1,270	1,350	1,435
60	900	1,050	1,200	1,275	1,350	1,420	1,485	1,550	1,620
70	1,350	1,475	1,600	1,675	1,750	1,820	1,885	1,950	2,020
80	1,750	1,900	2,050	2,125	2,200	2,270	2,335	2,400	2,470
90	2,220	2,360	2,500	2,575	2,650	2,720	2,785	2,850	2,920
100	2,700	2,850	3,000	3,075	3,150	3,200	3,250	3,300	3,350
30-FOOT AND LARGER AVERAGE CROWN DIAMETER									
40	850	1,025	1,200	1,275	1,350	1,420	1,485	1,550	1,620
50	1,050	1,200	1,350	1,425	1,500	1,570	1,635	1,700	1,770
60	1,300	1,450	1,600	1,650	1,700	1,785	1,870	1,950	2,035
70	1,700	1,850	2,000	2,075	2,150	2,220	2,285	2,350	2,420
80	2,150	2,275	2,400	2,500	2,600	2,670	2,735	2,800	2,870
90	2,600	2,725	2,850	2,925	3,000	3,070	3,135	3,200	3,270
100	3,050	3,175	3,300	3,375	3,450	3,500	3,550	3,600	3,650
110	3,600	3,700	3,800	3,875	3,950	4,020	4,085	4,150	4,220

1/ Expanded from (6) by linear interpolation.

2/ Gross volumes include the merchantable stems of all trees 5 inches d.b.h. and larger to a 4-inch top diameter inside bark.

Table 9.--Composite aerial volume table for northeast Mississippi

(In cubic feet per acre[1/])

Average stand height (feet)	Crown closure percent								
	15	25	35	45	55	65	75	85	95
	10-FOOT AVERAGE CROWN DIAMETER								
30	190	310	430	560	690	810	940	1,060	1,180
40	230	380	530	690	840	990	1,140	1,300	1,450
50	260	440	620	800	980	1,150	1,330	1,510	1,680
60	300	500	690	890	1,090	1,290	1,490	1,680	1,880
70	340	570	800	1,030	1,260	1,490	1,720	1,950	2,180
80	380	640	890	1,140	1,400	1,650	1,910	2,160	2,420
	15-FOOT AVERAGE CROWN DIAMETER								
30	210	350	500	640	780	930	1,070	1,220	1,360
40	260	430	610	780	950	1,130	1,300	1,480	1,650
50	310	510	730	930	1,140	1,350	1,550	1,770	1,970
60	360	590	930	1,070	1,300	1,550	1,780	2,030	2,260
70	400	660	940	1,200	1,460	1,740	2,000	2,280	2,540
80	440	740	1,040	1,330	1,620	1,930	2,220	2,530	2,820
90	480	800	1,140	1,450	1,770	2,100	2,420	2,760	3,070
	20-FOOT AVERAGE CROWN DIAMETER								
40	270	450	630	820	1,000	1,190	1,370	1,550	1,720
50	320	540	750	970	1,190	1,410	1,630	1,840	2,040
60	360	610	860	1,110	1,360	1,600	1,850	2,100	2,330
70	410	680	960	1,240	1,520	1,800	2,080	2,360	2,610
80	450	760	1,070	1,380	1,690	2,000	2,310	2,620	2,900
90	500	840	1,190	1,530	1,870	2,220	2,560	2,900	3,220
100	540	920	1,290	1,670	2,040	2,410	2,790	3,160	3,500
	25-FOOT AVERAGE CROWN DIAMETER								
50	320	550	770	1,000	1,220	1,450	1,670	1,900	2,120
60	370	620	880	1,130	1,390	1,650	1,900	2,160	2,410
70	410	700	980	1,270	1,550	1,840	2,130	2,410	2,700
80	460	780	1,100	1,420	1,740	2,060	2,380	2,700	3,020
90	510	860	1,220	1,570	1,930	2,280	2,640	2,990	3,350
100	550	940	1,320	1,710	2,090	2,480	2,860	3,250	3,630

1/ Based on Girard form class 77. Gross volumes are inside bark and include the merchantable stem to a variable top not smaller than 3 inches i.b. Reprinted from (1).

Table 10.--Significance test for regression of field volume on photo volume

Source of variation	df	Sum of squares	Mean squares	F	Table value	
					5 percent	1 percent
ROCKY MOUNTAIN AND KENTUCKY TABLES						
Reduction due to regression	1	26,523,076	26,523,076	1/ 275.03	4.04	7.19
Residual	48	4,629,036	96,438			
Total	49	31,152,112				
Regression equation: $\hat{y} = 0.98X + 19.93$						
MISSISSIPPI TABLE						
Reduction due to regression	1	17,050,351	17,050,351	1/ 58.04	4.04	7.19
Residual	48	14,101,761	293,787			
Total	49	31,152,112				
Regression equation: $\hat{y} = 1.48X - 441.30$						

1/ Significant at the 1-percent level.

Table 11.--Significance test of multiple regression for Minnesota aerial volume table

Source of variation	df	Sum of squares	Mean square	F	Table value	
					5 percent	1 percent
Reduction due to regression	2	20,696,704	10,348,352	46.52 1/	3.20	5.09
Residual	47	10,455,408	222,455			
Total SS	49	31,152,112				

Regression: $\hat{Y}$ (volume) = $56.19X_1$(height) + $13.14X_2$(crown closure) - 2,135.

1/ Significant at the 1-percent level

SOME RECENT STATION PAPERS
Lake States Forest Experiment Station

Proceedings, Third Lake States Forest Tree Improvement Conference, Sept. 17, 18, 1957. Sta. Paper 58, 87 pp., illus. 1958.

Incidence of White Pine Blister Rust Infection in the Lake States, by D. B. King. Sta. Paper 64, 12 pp., illus. 1958.

Fire Fuels in Red Pine Plantations, by Loyd LaMois, Sta. Paper 68, 19 pp., illus. 1958.

Snow Behavior in Forests of Northern Minnesota and its Management Implications, by Sidney Weitzman and Roger R. Bay. Sta. Paper 69, 18 pp., illus. 1959.

The Forest Insect and Disease Situation, Lake States, 1958, by Gerald W. Anderson and Donald C. Schmiege. Sta. Paper 70, 18 pp., illus. 1959.

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Influence of ownership on forestry in small woodlands in central Wisconsin, by Charles F. Sutherland, Jr. and Carl H. Tubbs. Sta. Paper 77, 21 pp., illus. 1959.